Docket No.: 57357-016

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	:	
Boris A. MASLOV, et al.	:	
Serial No.: 09/966,102	:	Group Art Unit: 2834
Filed: October 01, 2001	:	Examiner: D.D. Le

For: ROTARY ELECTRIC MOTOR HAVING CONTROLLER AND POWER SUPPLY INTEGRATED THEREIN

DECLARATION OF GENE Z. RUBINSON UNDER 37 CFR 1.131

Commissioner for Patents
Washington, DC 20231

Sir:

1. I, Gene Z. Rubinson, have been employed continuously at the firm McDermott, Will & Emery since 1998. I have represented Wavecrest Laboratories, the assignee of the above-identified patent application, in matters regarding preparation and prosecution of patent applications.

2. Prior to June 11, 2001, I met with Dr. Boris A. Maslov for initial discussion of the subject matter of the above-identified application and related inventions. Pursuant this meeting, in cooperation with inventors Alexander V. Pyntikov and Jing Lu, Dr. Maslov prepared a detailed description of the proposed implementation of the invention in a confidential paper entitled "Integration of an electric motor with controller and power supply." That paper was written prior to June 11, 2001.

4. Due diligence was exercised from prior to June 11, 2001 to the filing date of the present application, October 1, 2001. On or about June 12, 2001, I studied Dr. Maslov's confidential paper and began preparation of a draft patent application. A first draft of the present application was completed on or about August 14, 2001. To my best recollection, one or more telephone discussions with Dr. Maslov for clarification purposes took place during this period. The draft application was forwarded to Dr. Maslov to be reviewed for accuracy by the inventors. I received the inventors' comments thereafter and completed corrections to the draft application on or about August 24, 2001. The corrected draft application was forwarded to Dr. Maslov shortly thereafter for final review. Additional minor changes were indicated by telephone on or about August 31, 2001. I requested inventor residence and citizenship information, as well as assignment information. This information was received September 14, 2001. Declaration and assignment forms were immediately prepared and forwarded for execution by the inventors, together with the specification and drawings of the application to be filed. The documents promptly were executed and returned. McDermott, Will & Emery filed the application with the United States Patent and Trademark Office on October 1, 2001.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 Title 18 of the

United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing therefrom.

March 4, 2003
Date

Gene Z. Rubinson
Gene Z. Rubinson
Registration No. 33,351

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For: ROTARY ELECTRIC MOTOR HAVING CONTROLLER AND POWER SUPPLY INTEGRATED THEREIN

DECLARATION OF BORIS A. MASLOV UNDER 37 CFR 1.131

Commissioner for Patents
Washington, DC 20231

Sir:

1. I, Boris A. Maslov, am one of the inventors of the United States patent application identified above and of the subject matter described and claimed therein.

2. Our invention as claimed in the subject application was conceived in this country prior to June 11, 2001, the filing date of U.S. patent 6,380,648 (Hsu). The Hsu patent has been relied upon by the U.S. Patent and Trademark Office for rejection of application claims under 35 U.S.C. § 102 for lack of novelty or, alternatively, under 35 U.S.C. § 103 for obviousness.

3. Prior to June 11, 2001, I met with patent attorneys, including Gene Z. Rubinson and Alexander V. Yampolsky, and discussed the subject matter of the above-identified application and related inventions with them. Pursuant this meeting, in cooperation with inventors Alexander V. Pyntikov and Jing Lu, I prepared a detailed description of our proposed implementation of the invention in a confidential paper

entitled "Integration of an electric motor with controller and power supply." One of the purposes of this paper was to provide outside counsel with disclosure of the invention to enable preparation of the patent application. Attached as Exhibit 1 is a true copy of the confidential paper. The paper bears a date, which has been redacted, that is prior to June 11, 2001.

4. I have reviewed the declaration by Gene Z. Rubinson and believe that the assertions made therein are accurate.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

2/05/2003
Date

Boris A. Maslov
Boris A. Maslov

Confidential

Integration of an electric motor with controller and power supply (016)

Authors: Boris A. Maslov, Alexander V. Pyntikov, and Jing Lu.

Abstract

Present invention relates to rotary electric motors where stator is located inside the motor and rotor rotates around the stator on the outside of the motor. There are many applications where such arrangements are beneficial, one example being propulsion applications in transportation, i.e. in-wheel hub motor arrangements. The invention deals with the design of a stator in such a way that there are hollow spaces inside the stator. Such a hollow spaces are used to place control system (position sensors, control logic circuitry, power electronics, protection circuitry etc.) and power source (batteries rechargeable or disposable, fuel cells, capacitors and ultra-capacitors, other chemical, mechanical, electrical etc. power sources) within the stator.

General Description

In many instances the placement of the rotor of the rotary electric motor on the outside of the motor provides valuable benefits for the specific application of this given motor. Basic theory of electromotors teaches that it is always possible to 'flip' the motor and trade places between rotor and stator in a given electric motor. In many cases there are severe technical limitations in doing so due to the necessity to bring electric power to the outside rotating parts of the electromotor. There are many ways to resolve these issues by using slip rings and other various brushed arrangements. Several classes of electric motors permit you to do so relatively easy when there is no need to provide electric energy to the rotor: switched reluctance motors, induction motors, permanent magnet DC and AC motors, some stepper motors etc. Special design always required ensuring that the rotor can perform being on the outside of the motor.

When one deals with such a motor where rotor is located on the outside, stator is normally designed to be a metallic yoke being either solid metal, stack of laminations, powdered composites or other magneto-conductive material. It is required for proper magnetic flux distribution with possible additional objectives of decreasing eddy current and other losses, easing heat dissipation, providing mechanical rigidity, manufacturability etc.

Present invention suggests to design a stator comprising of magneto-conductive materials of one or another arrangement in a way that a hollow area be left within the body of a stator. It is possible to design such an arrangement and still get required magnetic flux distribution within the stator yokes, one possible example is described in patent # (there could be a reference to one of already filed patents describing separated magnetic circuits). Once such a hollow place exists within the body of a stator, the control system and/or power source can be placed within the limits of the stator providing integration of the components required for any motor to operate (controls, power) in one place and hence providing a number of additional benefits. The examples of such benefits are:

- Decrease of parts count and simplification of integration of such a motor into specific application;
- Decrease or total elimination EMI (electromagnetic interference) from controls and stator windings (by shielding, grounding of pieces, enclosing etc.);
- Decrease of acoustic/mechanical noise from the motor;
- Decrease of total weight;
- Simplification of the use of such a combined motor in specific applications, i.e. in-wheel applications for transportation.
- Scalability, ability to cascade several motors together
- Safety: no exposure to main power voltage, protection from battery leaks, heat etc.
- Various charging options (you can charge as you go or when you idle, you can replace batteries etc.)

In some applications certain level of motor controls should remain outside of the motor, for example when human operator input is required (transportation) or variable speeds are needed (fans, conveyors). In such instances separate input module, representing a part of overall control system, can be placed outside of proposed integrated motor and linked with the rest of the motor by wires, cables, wireless or other communicational means.

By placing the controls and power source inside the motor, overall weight reduction is achieved and simplicity of motor' integration into specific application is provided. Usage and operating of such a motor is significantly simplified. The usage of such motors, specifically in propulsion applications, can be made scalable by placing several of such motors in synchronous operations (or 'cascading' motors) on the same axle of a vehicle.

Preferred Embodiments

One preferred embodiment is presented on Fig.1 with its exploded view on Fig. 1a. In this preferred embodiment the outside rotor comprises of fourteen (14) electromagnet poles forming seven electromagnet groups of two poles each. Energization is provided to the rotor windings via commutator brushes, such brushes being attached to the rotor and slip ring assembly being attached to the stator. Batteries are located within the stator and are electrically connected to the slip rings. Brushed arrangement eliminates the need for electronic commutation of the motor.

Fig. 2 exhibits another possible preferred embodiment of the invention with Fig. 2a containing an exploded view of the motor. In this preferred embodiment, outside rotor comprises of an annular ring of permanent magnet poles, 16 in number, with alternating polarities, such magnets being magnetized in radial direction. Inner part of magnets' surface comprises cylindrical airgap of this radial flux permanent magnet electric motor. Outside surfaces of permanent magnets are attached to the back iron ring comprised of solid metal magneto-conductive material, ring of conventional steel in a preferred embodiment.

Stator consists of stator groups, 7 in number, each group consisting of two salient electromagnet poles allocated in tangential direction along the circumference of the airgap. Each electromagnet pole of the stator group contains separate winding of a number of turns of insulated copper wire, both windings of a stator group connected in such a way that poles of a stator group are magnetized in opposite directions when the windings are energized. Each stator group is connected to the center shaft of the motor, which in turn provides the connection of the motor (stator) to the vehicle frame in a conventional transportation application. Hollow area exists within the stator in this preferred embodiment where control system and power sources can be placed.

Control system consists of seven power modules, one for each stator group of two poles, each module is assembled on a separate printed circuit board (PCB) and mounted within the stator in a close proximity to the stator group it provides excitation to. Such an arrangement provides even further decrease of EMI compare to the preferred embodiment as on Fig. 1. Position sensing is provided by Hall effect sensors with direct connections of appropriate sensors to individual power stage PCBs. Under such arrangements central control unit may not be necessary if only simple torque/speed controls are desired. That is the case for the preferred embodiment of Fig. 2. The existence of separate stator groups and separate power modules attached each to the corresponding to it stator group, increases redundancy of the motor in case of individual stator groups or power module malfunctions, it also increases reparability, upgradeability, and replaceability of the motor because each individual stator group can be replaced (attached, detached) independently of others.

Power unit consists of rechargeable NiMH cylindrical batteries placed in the hollow areas of the stator and connected to the control system and stator coils. The same recharge and replacement options for the power unit exist as for the preferred embodiment on Fig. 2.

Preferred embodiment on Fig. 3 with its exploded view on Fig. 3a shows the arrangement similar to Fig. 2 whereas energization to the pole group consisting of two electromagnet poles is provided by one winding per pole group. Hall sensors are shown which provide position sensing in this preferred embodiment.

The stator is designed in such a way that there is a space within its boundaries, which is not used to conduct magnetic flux of the motor. This space is used to place inside the stator the control system of the motor. In this preferred embodiment the position sensing is provided with Hall sensor elements attached to the stator elements along the circumference of the airgap. Other arrangements, including but not limited to absolute resolvers, encoders, and incremental encoders, optical, mechanical, electrical position sensors and their combinations, may be used as well. Position sensing signals are delivered to the control system of the motor installed inside the stator. The control system is electrically grounded to the ground common with stator elements, and preferably with rotor elements. Control system consists of power stages of full H-bridges of MOSFET transistors, which are controlled by gate drivers' circuitry. Pulse-Width-Modulation (PWM) technique is used to control the excitation profiles of individual windings of stator elements. Each gate driver circuitry is controlled by and overall motor controls are provided with the central processor unit (CPU), which can be implemented with micro controller unit (MCU), digital signal processor (DSP) or otherwise. Outputs of H-bridges are directly connected to individual winded coils of stator elements and PWM-modulated power feed is delivered to these coils to operate the motor according to implemented by CPU algorithms. This provides one important benefit of limiting 'common mode' electromagnetic interference, which is always present when the controller is located outside of the motor and PWM-modulated main power is delivered to stator coils over power cables. The cables itself are the sources of such EMI and their shielding presents significant engineering challenge not always easily achievable. Grounding of electromagnetic components of stator and rotor elements along with the control circuitry also decreases possible EMI. Additionally, when the motor is assembled and placed into particular application, additional overall electromagnetic shielding via coating or encapsulation in a conductive material may be applied.

Fig. 4 shows the electric motor assembly for motors on Fig. 1-3 or similar embodiments. Outside rotor cover is manufactured from electrically conductive material, which can be steel, aluminum, alloys, composite materials with metallic conductive particles in it, or other similar arrangements. This conductive cover provides additional shielding from EMI and may or may not be grounded to the common ground.

In cases when mobile power is needed for the motor to operate (as opposed to the stationary electricity grid power supply) such a mobile power can also be placed within the motor itself along with control system. It can be rechargeable or disposable batteries, capacitors or ultra-capacitors, fuel cells, or other available sources of electric power. In a preferred embodiment, the set of rechargeable Li-Ion batteries is used to provide mobile power to a wheel of a vehicle using such a wheel. Such a battery set could be recharged while the motor is not operating; it can be charged while the motor is in operation and outside extra supply of electric power is present; it can be charged with a regenerative braking type of operations when wheel is reversed and effectively acts as a generator (one such usage would be to provide a braking for the vehicle using such a wheel). Batteries can be replaced (swapped) with fully charged when the original set is discharged, or other arrangements can be implemented. The placement of electric power source within the motor provides several important benefits, some of which are:

- Electric safety for humans: human operators/users are not exposed to main electric power voltage and are hereby protected from its possible hazardous effects.
- Chemical safety for humans: in case of malfunctions a battery could leak or explode thus exposing humans to hazardous chemicals comprising such a battery.
- Thermal safety for humans: in some instances batteries are getting extremely hot during normal operations, in some cases it can be a result of malfunction; in all cases humans are better protected from hazardous heat from electric power source when it is encapsulated within the motor.

There often is a requirement for electric motors to have a low level of mechanical noise while operating. It is particularly true when operating a vehicle, say electrically propelled vehicle with wheels being integrated with motors of the proposed arrangements. Traditionally, mechanical noise arises from the rotation of the motor itself, from the mechanical connections of the motor to the frame/placement, from connecting cables and their attachments, from control system and its attachments, and from power source and its attachments. By integrating of all the above components into one unit the mechanical noise can be significantly decreased. Moreover, special control algorithms can be implemented which decrease the level of mechanical noise for such an assembly by fine-tuning the profiles of electric excitation delivered to each individual coil of stator elements.

Block-diagram of the control system for the motors shown in Fig. 1-4 is illustrated on Fig. 5 with typical electronic switch known as H-bridge shown on Fig. 6.

Simplified preferred embodiment of the control system is shown on Fig. 7. It is applicable to the motors shown on Fig. 1-4. Seven independent H-bridges are connected to seven (7) stator windings. Arrangement of 14 Hall sensors, two per each independent phase, provides position sensing. Voltage regulation is common for all phases and

provided by one PWM voltage regulator. There is no DSP, no current feedback, and no speed sensing. The working of the control system is done with the simplified algorithm calling for each phase to be turned on or off only according to the relative position of the rotor to the stator element, such relative position is determined by two hall-effect sensors per commutating phase. This is simplified arrangement, which permits for the motor to operate but does not provide for various commutating algorithms to me implemented electronically. Should one desire to change the working of the motor, mechanical adjustments of hall-effect sensors will be needed.

Another block-diagram of the control system, which can be implemented to drive motors shown in Fig. 2-4, is illustrated on Fig. 8 where Sequence Controller directs each individual electronic switch set according to the control algorithm and specific position of the rotor with respect to the stator, such position information provided by the position feedback.

Preferred embodiment of the control system for the motors shown in Fig. 2-4 is illustrated on Fig. 9. Seven independent coil windings shown on Fig. 3 (or two of the coils belonging to the same stator element, which are connected in series as described above to create alternating polarity of magnetic field at the stator poles on Fig. 2) are independently connected to seven outputs of H-bridges of the control system. Each H-bridge is independently controlled by its own gate driver, which in turn is driven by independent PWM generator. Each PWM generator is supplied with the electric power by the independent power supply (battery) Vs1 – Vs7. PWM generators and gate drivers are controlled by Digital Signal Processor (DSP), in this preferred embodiment is it Texas Instruments TMS320 family DSP. Feedback signals are needed for DSP to control the motor properly, in the preferred embodiment these signals are the rotor position signal (theta(t)), angular velocity signal (omega(t)) and seven current feedback signals one per each independent excitation phase. Position sensing is provided by fourteen (14) Hall effect sensors located along the circumference of the airgap and connected to DSP. Angular velocity signal is then derived from position sensing signals by processing these signals at DSP. Current sensing is achieved by Hall effect-based non-contact current sensors located one per each independent phase. These analog current sensing signals after proper amplification are directed to DSP for further processing. The DSP determines for all seven circuits (phases) the exact profiles of PWM signals and timings of gate drivers ON-OFF states independently for each of the seven phases subject to the specific algorithm under the implementation by DSP. Such algorithms can me downloaded to DSP from time to time, or can be dynamically selected by DSP from currently available at DSP selection for immediate execution. A variety of different algorithms can provide for different excitation profiles of PWM and gate drivers so the motor under the control can achieve various required performance characteristics by the means of the electronic controls.

PWM generators are in fact fast electronic switches turning power Vs1 – Vs7 on and off at high frequency. To avoid associated with PWM switching acoustic noises, such switching frequency is conventionally selected in 22-45 kHz range. PWM-frequency signals after proper profiling by DSP are directed to gate drivers, which in turn control H-

bridges operations. H-bridges commutate mail power supplied from the battery to the windings at this high PWM-frequency. Commutating of main electric power generates significant electromagnetic emissions associated with this base PWM-frequency, so-called common mode frequency and common mote EMI/noise. In conventional motor arrangements H-bridges (and associated with it controls) are located outside of the motor and cables leading from H-bridges to the motor windings are the major source of common mode EMI. In proposed invention all H-bridges are located within the stator, so the wires leading from PWM to the windings are substantially shorter, in addition effective shielding of the whole motor is possible. In fact, H-bridges can be placed individually on each stator element, as shown on Fig. 3. Combination of these factors provides substantially smaller common mode noise compare to conventional motors, which provides substantial improvement over the existing arrangements.